The Out of Africa conference

U-Pb ages, Pb-Os isotopes and platinum-group element (PGE) composition of Mailaka picritic basalt to rhyodacite volcanic sequence, West-Central Madagascar LIP

C. Cucciniello[1], A. Langone[2], L. Melluso[1], V. Morra[1], J. J. Mahoney[3], T. Meisel[4] and M. Tiepolo[2]

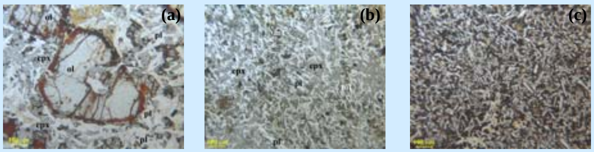
[1]Dipartimento di Scienze della Terra, Università di Napoli Federico II, Via Mezzocannone 8, 80134 Napoli, Italy - [2]Dipartimento di Scienze della Terra, Università di Pavia and CNR - Centro di Geoscienze e Georisorse, Via Ferrata 1, 27100 Pavia, Italy - [3]School of Ocean and Earth Science and Technology, University of Hawaii at Manoa,1680 East-West Road, Honolulu, HI 96822, USA - [4]General and Analytical Chemistry, Montanuniversität Leoben, Austria

Introduction

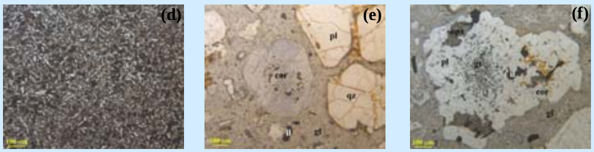
The Madagascan Large Igneous Province (LIP) represents one of the major magmatic events in the Late Cretaceous. Its formation was related to the break-up of Madagascar and Greater India (Storey et al., 1995; Torsvik et al., 1998). Late Cretaceous igneous rocks are preserved along the rifted margin of the eastern coast, in the Mahajanga and Morondava basins and directly above the Precambrian basement (**Fig.1**). Recent geochronological data (U-Pb and ^{40}Ar-^{39}Ar) show that the Madagascar LIP spanned ages between 92 and 84 Ma (Storey et al., 1995; Torsvik et al., 1998). The Madagascar LIP consists of lava flows, dykes, sills and intrusive complexes. The chemical composition of igneous rocks is broadly bimodal, with predominant mafic and subordinate silicic rocks.

The Mailaka lava succession outcrops in the central-western Madagascar along the rifted margin of the Morondava basin and covers a large area (**Fig.1**). It consists of thick (~ 150 m) monotonous succession of lava flows (with columnar jointing), that dips gently westward. The lava succession covers the Early Cretaceous Mailaka Limestone Formation. Dacitic and rhyodacitic lavas (pitchstone) are volumetrically minor and outcrop near Maintirano. Toward the south, the succession appears to decrease in thickness and the rhyodacitic flows are absent. Dykes outcrop in the Permo-Triassic sedimentary rocks of Morondava basin and along the boundary close to Precambrian basement. The dykes reach 10 m in width, are randomly oriented and often cross-cut each other. Sills (of gabbroic composition) intrude the Mailaka Limestone Formation. The Precambrian basement of the area consists of ~2.5 Ga gneiss interlayered with 820-740 Ma granitoid and gabbros, pervasively deformed and metamorphosed to granulite-facies between ~750 and 500 Ma (Tucker el., 1999b).

Petrography



(a) picritic basalt **(b)** transitional basalt **(c)** basaltic andesite



(d) andesite **(e)** rhyodacite **(f)** rhyodacite

Photomicrographs of the Mailaka volcanic rocks.

ol = olivine
cor = cordierite
cpx = clinopyroxene
opx = orthopyroxene
pl = plagioclase
mt = magnetite
qz = quartz
il = ilmenite
gt = garnet
gl = glass

Pb-Os isotope ratios and PGE composition

The Pb isotope ratios in Mailaka transitional basalts exhibit very little variations in ^{206}Pb/^{204}Pb (17.936-18.195), ^{207}Pb/^{204}Pb (15.473-15.492) and ^{208}Pb/^{204}Pb (37.858-37.951). Sample M104 has relatively lower ^{206}Pb/^{204}Pb (17.606) and ^{208}Pb/^{204}Pb (37.594) than the other transitional basalts, but similar ^{207}Pb/^{204}Pb (15.437). In the ^{206}Pb/^{204}Pb vs.^{207}Pb/^{204}Pb diagram (**Fig.5**), data for the transitional basalts overlap the field defined by Indian MORB (Mahoney et al.,1992). In contrast, the tholeiitic basalts show different Pb isotopic compositions (^{206}Pb/^{204}Pb = 17.194-17.618; ^{207}Pb/^{204}Pb =15438-15.530; ^{208}Pb/^{204}Pb = 37.338-37.727). In Pb-Pb isotope space (**Fig.5**) the data plot to the left of the 4.55 Ga Geochron and above the Northern Hemisphere Reference Line (NHRL). The intermediate and evolved rocks display a restricted range in ^{206}Pb/^{204}Pb (18.978-19.156), ^{207}Pb/^{204}Pb (15.702-15.707) and ^{208}Pb/^{204}Pb (39.023-39.161; **Fig.5**). Andesite M160 shows a different Pb isotopic composition. It differs from the other intermediate and evolved rocks in having lower ^{206}Pb/^{204}Pb (16.151), ^{207}Pb/^{204}Pb (15.274) and ^{208}Pb/^{204}Pb (36.668; **Fig.5**). The transitional basalts exhibit low concentrations in PGE (Ir = 0.11-0.3 ng/g, Ru = 0.14-0.17 ng/g, Pt = 1.19-2.29 ng/g and Pd = 0.97-1.64 ng/g). In addition, the transitional basalts have Os isotopic compositions (^{187}Os/^{188}Os$_i$ = 0.1389-0.1398) and Re contents similar to those observed in many mid-ocean ridge basalts (e.g., Escrig et al., 2004; **Fig.6**). In contrast, the tholeiitic basalt has more radiogenic Os (^{187}Os/^{188}Os$_i$ = 0.1609).

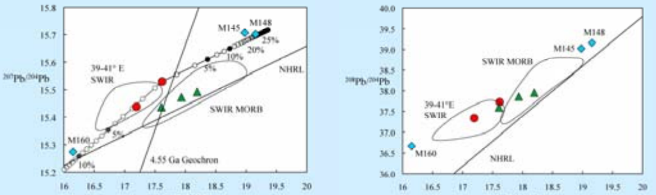


Fig. 5

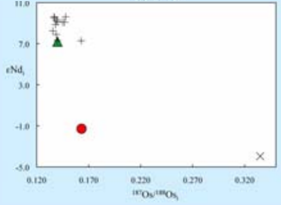


Fig. 6

● tholeiitic basalts
▲ transitional basalts
◆ intermediate and evolved rocks
+ Central Indian Ridge basalts
× 39-41°E South West Indian Ridge (SWIR) basalt

Discussion

The intermediate and evolved rocks of Mailaka lava succession show large variations in Pb isotopic ratios and this rule out the possibility that their range of elemental compositions could be due to closed-system fractional crystallization of basic parental magma. The presence of inherited older zircons and cordierites in the rhyodacites clearly indicate the involvement of a crustal component in their petrogenesis. The high Zr, Y and HREE content in the rhyodacites should exclude the hypothesis that the rhyodacites represent the product of partial melting of crustal rocks in presence of residual garnet (Melluso et al., 2001). The most plausible petrogenetic process to generate the evolved rocks is extreme fractional crystallization, starting from a basaltic parental magma, with coupled assimilation of wall rock (AFC). AFC model for intermediate and evolved rocks is displayed in **Fig.5**. The AFC vectors indicate ~ 25% assimilation of upper crust in the genesis of rhyodacites (black curve) with rate of assimilation (r) of 0.35, whereas ~ 8% assimilation of lower crust (grey curve) with r of 0.1 for genesis of the andesite with low Pb isotope ratios.

Conclusions

U-Pb zircon ages for rhyodacites of Mailaka lava succession demonstrate that silicic volcanism in this region is contemporaneous with the Madagascan LIP. The variations in Pb isotope ratios in the andesites and rhyodacites, show clearly that their magmatic evolution were under open-system conditions (AFC). In addition, chemical and isotopic differences between andesite M160 and the other evolved rocks suggest distinct crustal end-member in their genesis. However, interaction of mantle-derived magmas with different crustal lithologies of the Madagascan crust is expected in this sector of the flood basalt sequence.

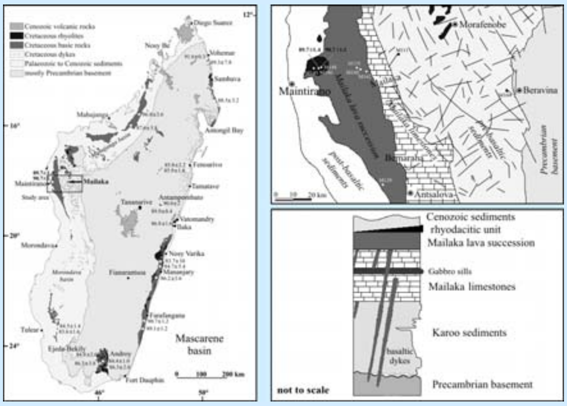


Fig. 1

Zircon U-Pb age

Zircons from sample M146 are mostly euhedral, with a prismatic habit and generally fractured. Most grains exhibit well-developed oscillatory zoning typical of growth under magmatic conditions (**Fig. 2**). A few zircons are characterized by dark cores and brighter rims with faint oscillatory zoning. A total of 44 U-Pb analyses were carried out on thirty-one zircon grains. Isotopic results gave 29 U-Pb concordia ages ranging from 70 to 1075 Ma, with a major cluster between 84 to 96 Ma (**Fig. 3**). This cluster shows a mean concordia age of 89.7 ± 1.4 Ma (MSWD - Mean Square Weighted Deviation = 0.054; probability of concordance = 0.82; **Fig. 3**). The oldest concordant ages (183 to 1075 Ma) belong to inherited zircons, whereas the youngest (70 to 82 Ma), mainly obtained from fractured zircons, are probably related to variable Pb loss.

A total of 35 U-Pb analyses were performed on 25 zircon grains from sample M148, and the results are mostly concordant (25 analyses) and range between 79 to 576 Ma (**Fig. 4**). Eighteen concordant data point yield ages of 90.7 ± 1.1 Ma (probability of concordance = 0.66; **Fig. 4**). The youngest concordant ages (79 to 80 Ma) are probably due to minor Pb loss. The oldest concordant ages (446 to 576 Ma) belong to zircon grains inherited from the juvenile Pan-African continental crust (e.g. Cox et al., 2004).

The U-Pb zircon data obtained in this study show a very consistent pattern of high-precision ages. The age determinations obtained from two rhyodacites of Mailaka are identical within error with the U-Pb age of the Analalava gabbro intrusion (91.6 ± 0.3 Ma; Torsvik et al., 1998) and Antampombato-Ambatovy complex (90 ± 2 Ma; Melluso et al., 2005).

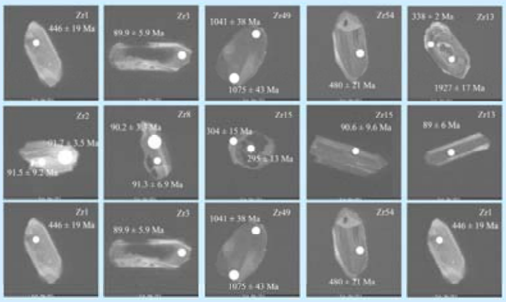


Fig. 2

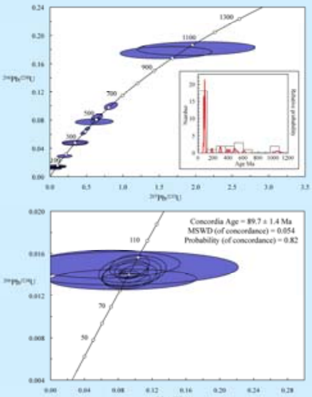


Fig. 3

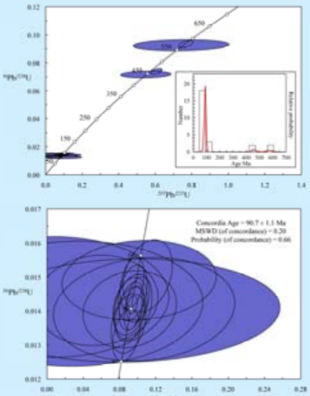


Fig. 4

References

Cox, R., Coleman, D.S., Chokel, C.B., DeOreo, S.B., Wooden, J.L., Collins, A.S., De Waele, B. and Kröner, A. 2004. Proterozoic Tectonostratigraphy and Paleogeography of Central Madagascar Derived from Detrital Zircon U-Pb Age Populations. The Journal of Geology, 112, 379-399.

Escrig, S., Capmas, F., Dupré, B. & Allègre, C. J. 2004. Osmium isotopic constraints on the nature of the DUPAL anomaly from Indian mid-ocean-ridge basalts. Nature, 431, 59-63.

Mahoney, J.J., le Roex, A. P., Peng, Z. X., Fisher, R. L. & Natland, J. H. (1992). Southwestern limit of Indian Ocean ridge mantle and the origin of low ^{206}Pb/^{204}Pb MORB: isotope systematics of the central Southwest Indian Ridge (17°-50°E). Journal of Geophysical Research, 97, 19771-19790.

Melluso, L., Morra, V., Brotzu, P. & Mahoney, J.J. 2001. The Cretaceous igneous province of central-western Madagascar: evidence for heterogeneous mantle sources, crystal fractionation and crustal contamination. Journal of Petrology, 42, 1249-1278.

Melluso, L., Morra, V., Brotzu, P., et al. 2005. Geochronology and petrogenesis of the Cretaceous Antampombato - Ambatovy complex and associated dyke swarm, Madagascar. Journal of Petrology, 46, 1963-1996.

Storey, M., Mahoney, J.J., Saunders, A.D., Duncan, R.A., Kelley, S.P. & Coffin, M.F. 1995. Timing of hot spot-related volcanism and the breakup of Madagascar and India. Science, 267, 852-855.

Torsvik, T.H., Tucker, R.D., Ashwal, L.D., Eide, E.A., Rakotosolofo, N.A. & de Wit, M.J. 1998. Late Cretaceous magmatism of Madagascar: paleomagnetic evidence for a stationary hotspot. Earth and Planetary Science Letters, 164, 221-232.

Tucker, R.D., Ashwal, L.D., Handke, M.J., Hamilton, M.A., Le Grange, M., Rambeloson, R.A., 1999b. U-Pb geochronology and isotope geochemistry of the Archean and Proterozoic rocks of north-central Madagascar. Journal of Geology, 107, 135-153.